# Biological comments on the US EPA's 2011 proposed rule for cooling water intake structures at existing facilities

PISCES CONSERVATION LTD

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# Summary

This report presents an analysis of certain biological issues relating to the EPA proposed rule for existing facilities published on April 20, 2011 (67 Fed. Reg. 22,174). The main areas of focus of this report are (1) the adverse environmental effects of cooling water intake structures and EPA's assessment of those effects; (2) the proposed rule's permit application and monitoring requirements; (3) the proposed rule's impingement requirements; and (4) an assessment of the technologies available to minimize entrainment mortality.

The analysis was undertaken by Pisces Conservation Ltd, which was established in 1995 by environmental science staff from the United Kingdom power industry and major universities. The company specialises in the ecological effects of industry, and power plants in particular, on the aquatic environment. Pisces has extensive international experience, including more than 12 years of study on power plants in the Hudson valley and has worked on issues in several other areas of the USA. Pisces also has a specialist ecological software section that develops computer programs for the analysis of ecological data, which are used world-wide.

Our main conclusions are as follows:

1. EPA's analysis of the impact of once-through cooling is inadequate because it underestimates aquatic impacts beyond just impingement and entrainment. Although the main focus of EPA's proposal is to reduce impingement and entrainment, cooling water intakes affect many other components within the local ecosystem and can potentially produce a much wider range of adverse effects on fish, crustaceans and top predators such as birds, as well as decomposers at the bottom of the ecological hierarchy. Such changes are difficult to detect and document, have been little studied, and may be hidden by other anthropogenic impacts. EPA acknowledges the ecological effects of intake structures, but a fuller description of those impacts is warranted. Without a more robust analysis, EPA cannot and has not adequately considered the benefits of closed-cycle cooling.

In addition, EPA's age 1 equivalence calculations suffer from many problems relating to the age, quality, analysis and extrapolation of the data. As a result, the agency's estimates of age 1 equivalent fish killed by power plants is unreliable and is likely an underestimate, potentially a significant underestimate, of the actual mortality numbers. The age 1 equivalent metric, even when accurately estimated, fails to account for the ecological effects because it ignores species other than fish and fails to take proper account of the ecological value of forage fish as fodder for other organisms.

2. Survival after impingement or entrainment is difficult to measure. It has many factors which need to be controlled to make the data useful. Probably the 2 most important are how

the animals are chosen to be entered into the survivorship trial, and second how long the trial continues. The EPA is suggesting 24-48 Hours. This may well lead to an underestimate of the number of fish killed by impingement. Damaged fish may die over a long period after impingement, with studies up to 96 hours still showing on going mortality.

3. The impingement requirement of the proposed rule still allows fish to be impinged. Although it is possible to reduce impingement at many sites using various technologies, reducing the volume of water extracted is the surest way to reduce impingement. For all other methods, effectiveness will be site-specific, variable, and liable to differing interpretation. Nonetheless, short of reducing intake volume through closed-cycle cooling, the most reliable and measureable method of reducing impingement mortality is to reduce intake velocity sufficiently to prevent impingement from happening in the first place, rather than allowing impingement to occur and attempting to return fish to the waterbody unharmed.

4. Reductions in intake velocity will have little or no effect on levels of entrainment. All methods based on filtering out planktonic life forms to reduce entrainment at large intakes are problematic and unreliable. The area of screening needed to fine filter the volumes of water used by once-through cooling systems is very large, and because of this poses many operational difficulties. How the rule will be implemented in flowing environments is unclear. The surest method to reduce entrainment is to reduce the amount of water extracted by the plant. The best method for volume reduction is the use of closed-cycle cooling. For example, using cooling towers will reduce the volume of cooling water extracted by well over 90%. With these lower flows, other protective technologies such as wedge wire screens become practical to almost completely eliminate impingement and entrainment.

# 1 Adverse environmental impacts of cooling water intake structures.

## 1.1 Introduction

The use of direct cooling (i.e., once-through cooling) at power stations kills fish in several ways, most directly through impingement and entrainment. Water taken into the station for cooling is screened to remove large objects, including fish. Fish can sustain injury or death by entering intakes with the cooling water flow and then making physical contact with screens or filters. The trapping of fish on screens is termed impingement, and the death of fish in this way is termed impingement mortality. Water that passes through the screens and then through the station's cooling system to be discharged back into the environment holds small fish, fish larvae and other microscopic organisms, which may suffer injury or death through physical contact, rapid pressure change, sudden increase in temperature and chemical poisoning from biocides and other chemicals introduced into the water. The process of passage through the power station is known as entrainment; the death it causes is known as entrainment mortality.

## 1.2 Effects at the ecosystem level

The main focus of the EPA proposal is to reduce the direct effects of cooling water intakes on fish impingement and entrainment. However, cooling water intakes affect many components within the local ecosystem and can potentially produce a wide range of impacts, many of which are difficult to foresee. Some of these changes can lead to indirect effects on fish, crustaceans and top predators such as birds, as well as decomposers at the bottom end of the ecological hierarchy. Such changes are difficult to detect and document and have been little studied (a comprehensive review of knowledge up to 1983 is given in Langford (1983)). For many localities these changes have been hidden by other anthropogenic impacts because cooling water intakes have rarely been sited in pristine natural waters in which the local ecology has been studied prior to construction. Some of these indirect effects have been introduced above and will be brought together in this section from an ecosystem viewpoint. At the outset we need to be clear about how we can detect ecosystem-level effects rather than changes in individual species populations.

While an individual organism can clearly be observed to respond to stress, it is by no means clear that such a concept can be applied to an ecosystem. It is clear that ecosystems can be damaged by human activities and even completely destroyed, but is it possible to detect changes that demonstrate that the ecosystem is being placed under stress and ultimately suffering damage? Ulanowicz (1996) argues that ecosystem stress can be defined as an inhibition or reversal of the natural succession as characterised by Odum (1969). The main characteristics of this natural succession can be listed as:

1. Increasing species richness;
2. progressively greater trophic efficiency;
3. a richer structure for recycling materials;
4. more intense system activity;
5. greater trophic specialisation.

At the base of aquatic ecosystems there are the primary producers and the decomposer organisms. The primary producers can be divided between the large plants such as seaweeds and angiosperms, which normally are fixed to the substrate and are limited to shallow waters and the terrestrial fringe, and the planktonic, often single-celled algae, protozoans and bacteria. The decomposers, which are particularly active in the substrate, comprise fungi and bacteria. Energy input into the system is derived from light, and from autochthonous material such as leaves and wood and human waste which is often terrestrial in origin. Both the primary producers and decomposers are used as food by a wide range of organisms. In the plankton, small crustaceans such as copepods are particularly important. A wide range of benthic worms, insects and filter feeders consume the decomposers. These primary consumers are fed on by small predators such fish, insects and larger crustaceans that are in turn the food for large fish, mammals and birds.

This general scheme is found in all shallow waters and is highly adaptable in that the relative size and ecological activity of the different components can change dramatically between localities. In some areas, with large allochthonous inputs, the decomposers can dominate, while in other waters the planktonic primary producers may be dominant at the base of the food web. The presence of a cooling water intake can influence the relative size and economy of the different components within an aquatic ecosystem. The general routes by which a cooling water system may stress the local ecosystem are as follows:

1. Differential mortality of different species, resulting in changes in competitive ability.
2. The destruction of primary producers, resulting in reduced production.
3. The destruction of planktonic primary consumers, resulting in impoverished plankton.
4. Destruction of prey for juvenile fish, resulting in decreased food supply for various life stages of fish
5. The release of large numbers of dead planktonic organisms with the discharge water, resulting in an enhanced energy input into the decomposer system.
6. Changes in the temperature, oxygen concentration and other physical variables that change the rate of ecological activity and relative competitive advantage between species.
7. The alteration of flow regimes and associated physical variables such as sediments that can result in a shift in species composition.
8. The creation of fixed structures that can act as reefs and change the species composition.
9. The introduction of large areas of hard surface on intake pipes, docks, cooling tower slats and other structures, that can be colonised by organisms not normally abundant in the system.

 

10. The displacement of organisms, materials and nutrients from around the intake to the area of discharge resulting in the establishment of a non-equilibrium or unusual community in the discharge area.

This list is by no means complete, but it gives a feel for the wide range of impacts cooling water systems have on the local aquatic ecology. One way by which the impact of a power station can be appreciated is to visualise it as a giant, non-selective, filter feeder. It is rather like a whale that filters water and excretes to its environment, and offers a habitat to a wide gut flora and a skin that is colonised by barnacles and other parasitic organisms. Fish and other predators can be attracted to the vicinity of the whale because it stirs up the water and sediments and places their prey in exposed positions where they can easily be attacked. When it is argued that cooling water intakes are having no impact it is worth considering if it would seriously be suggested that a group of giant whales could be added to the same water body without appreciable impact.

Many of the arguments claiming that power plants have relatively insignificant effects are based on the concept of surplus production (i.e., the theory that fish produce more eggs than they need to maintain a stable population). From an ecosystem perspective, however, there can never be surplus production that can be removed from any component without impacting other parts of the system. It is self-evident that without the cooling water intake, other organisms would have consumed the production taken by the station (Boreman 2000).

An unusual example of the effect of a power plant at the ecosystem level is the study by Ulanowicz (1996) on creeks subject to discharges from a nuclear power station on the Crystal River, Florida. He noted that the greatest impact of the power station was on the highest trophic levels where the top predators, gulf flounder and stingray, either disappeared or changed their feeding pattern. There was clear evidence that the stressed system had reduced transfer efficiencies of energy from the lower to higher trophic levels. There was also a marked change in material recycling between stressed and natural creeks with faster recycling in the stressed system because material was retained at the lower trophic levels.

We know of no other studies that have attempted such a quantitative analysis of an ecosystem under stress from a power plant. However, there are considerable amounts of evidence indicating such aquatic ecosystem stress, typically reflected in a loss of top predators and a change in detrital and other low trophic levels concerned with recycling. The loss of top predators can be anticipated because of the efficiency of transference of production along food chains. This can be illustrated by a simple hypothetical example. A food chain in a pelagic system may comprise the following 4 components:

1. Primary producers
2. Planktonic crustaceans
3. Larval fish
4. Predatory fish.

 

Such a system is impacted most heavily by a cooling water intake via entrainment losses on the first 3 trophic levels. Each of these levels is affected both by the direct loss of individuals and also in the case of levels 2 to 4 by the reduced availability of food. A feature of all such trophic chains is that only a small part of the production at each trophic level is passed to the next highest level, and the result is relatively small flows to the top predators. For example, if a 10% transference efficiency is achieved, 1 g of carbon fixed by the primary producers would be transformed into 0.1, 0.01 and 0.001 g of carbon at the planktonic crustacean, larval fish and predatory fish levels respectively. If entrainment results in a reduction in standing crop sufficient to reduce transference efficiencies to 9% then the amount of production at the higher levels is reduced to 0.09, 0.0081 and 0.00073 g of carbon. Thus a 1% change in efficiency along the chain results in a 27% reduction of production at the predatory fish level. In general, at a large volume intake, stress on the ecosystem can be anticipated to produce just the types of impact noted by Ulanowicz (1996).

In reality, trophic structure is far more complex and species will be impacted to varying degrees. In general, longer-lived, slower-growing species tend to be more heavily impacted. These species may be replaced by faster-growing competitors. Such changes are characteristic of disturbed systems and generally result in reduced species richness and the efficiency of energy assimilation. While the outcome for particular species may be unpredictable, the essential feature remains: cooling water intakes entrain organisms over the full range of feeding behaviour from autotroph to top predator. Because they kill organisms at many trophic levels, their impact is similar to a general reduction in productivity and efficiency of energy transfer, the effects of which will be far greater towards the top of the food web.

From this perspective we can take a radically altered view of some oft-repeated arguments. For example, it has long been argued that entrainment losses of predatory fish, such as striped bass, were acceptable because density-dependent mortality was acting, so that the fish killed by entrainment would not have survived anyway due to food limitations. If the effect of large-scale once-through cooling is to reduce production and energy transference, then density-dependent mortality could be viewed as the end result of a food shortage and thus, by the power plant reducing the food availability, an indirect effect of entrainment acting at lower trophic levels.

The above discussion has focused on energy flux along food chains. Planktonic plants, crustaceans and larval fish are particularly vulnerable to entrainment, and can be killed in large numbers. Their loss results in an increased flux of resources to the decomposers (some of which is also derived from dead pieces of larger organisms broken-up by the cooling water system). The net result of reduced energy flux to the top predators and increased decomposer activity is an ecosystem dominated by simpler organisms. Notably, this promotion of decomposer forage at the expense of higher consumers is characteristic of the ecological stresses which in large part prompted the 1972 Clean Water Act amendments.

## 1.3 *Impingement and entrainment of fish and shellfish*

An immediate problem that arises relates to the comparison of the importance of the deaths of young stage and adult fish. It is generally accepted that the loss of an egg is not as damaging to the population as the loss of a mature female about to spawn. To overcome this issue the EPA converted the numbers of entrained and impinged fish into age 1 equivalent (A1E), as explained below:

> *"Age-1 Equivalents*
> *The Equivalent Adult Model (EAM) is a method for converting organisms of different ages (life stages) into an equivalent number of individuals in any single age (Goodyear 1978; Horst 1975). For its 316(b) analyses, EPA standardized all I&E mortality losses into equivalent numbers of 1-year-old fish, a value termed age-1 equivalents (A1Es). This conversion allows losses to be compared among species, years, facilities, and regions.*
> *To conduct EAM calculations requires a life history schedule, for each species, incorporating age-specific mortality rates. Using these species-specific survival tables, a conversion rate between all life history stages and age 1 is calculated. For life history stages younger than 1 year of age, the conversion rate is calculated as the product of all stage-specific survival rates between the stage at which I&E mortality occurs and age 1. Consequently, the loss of an individual younger than age 1 results in a conversion rate less than 1. For individuals older than 1 year, the conversion rate is calculated as the quotient of all stage specific survival rates between the stage at which I&E mortality occurs and age 1. Consequently, the loss of an individual older than age 1 results in a conversion rate greater than 1."*

(Section 3.2.2.1. EPA Environmental and Economic Benefits Analysis for Proposed Section 316(b) Existing Facilities Rule EPA 821-R-11-002 March 28, 2011 )

The EPA then goes on to give values to these fish in terms of forgone fishery yield, and production forgone. Fishery yield is a measure of the biomass harvested from a cohort of fish. EPA expressed I&E mortality of harvested species in terms of forgone (lost) fishery yield. Production forgone is an estimate of the biomass that would have been produced had individuals not been impinged or entrained.

### 1.3.1 Problems with age equivalence methods

Using an Age 1 equivalent method like the one EPA proposes only produces reliable results when the underlying data as complete as possible, and includes:

- Good estimates of entrainment and impingement numbers
- Data split into the correct life stages
- Accurate survivorship factors from stage to stage.

These individual requirements are discussed in detail below, together with additional problems caused by species identification and extrapolation to other sites.

#### 1.3.1.1 Impingement and entrainment data quality

The entrainment and impingement data used in EPA's estimates have, by necessity, been extensively corrected to account for problems found in the sampling methods, such as day/night differences and seasonality. The corrections have all been applied to the data to improve their quality, before the age 1 equivalent method is undertaken.

However, there are still many issues with the quality of the data EPA used. Many of the data sets used in the calculations are old, collected in the 1970s and 80s. There have been many changes, both for the better and worse since that time. For example, in examining fish populations in the Hudson River in New York, many species have been found to be trending either up or down over the 30-year period of the studies. Taking the numbers of fish killed by a power station on the Hudson in the 1980s would give very misleading results compared to the populations of fish in the river now. In some cases the habitat around the site has changed over the life of the station. For example the Lovett Steam Generating Plant used to operate near the Indian Point nuclear plant. Lovett has now closed, ultimately taking a large "predator" out of the water and potentially changing the impact Indian Point has on aquatic life.

#### 1.3.1.2 Data split into correct life stages

Entrainment data were split into age classes at nearly all stations where data exists. There are, however, problems with the identification of some species at the egg and larval stages (e.g. blueback herring and alewife are treated as "river herring"). The impingement data are sometimes collected with all the age classes separated, but aging fish is often an inexact science and can be difficult and time consuming. Therefore, questions remain as to whether EPA has the data been able to adjust impingement and entrainment data to age 1 equivalents properly to allow a complete assessment to be made.

#### 1.3.1.3 Accurate survivorship factors

Many of the survivorship factors used in the calculation of A1E fish are based on back-calculations that assume a stable population. This is a dubious assumption as there have been major environmental changes in the last 40 years. If, for example, the entrainment data are from the 1970s, before the Clean Water Act significantly improved water quality, the populations of fish could have been suppressed by the poor water quality rather than natural mortality rates. This could have lead to a significant underestimation of the survival factors of the fish from stage to stage. Another factor that can affect the survival estimates is that survivorship may well vary between sites; a species in the middle of its geographical range may have a very different survivorship at each age to one which is close to its geographical limit. This is important as when dealing with the survival of a fish, from age class to age class, small differences in the parameters used to calculate A1E can make large differences to the final estimates.

#### 1.3.1.4 Not all species are always reported or identified

Many of the studies in the US do not report all species caught. This can be for many reasons, such as difficulty in identification, damage, or simply lack of space in the report. This can result in some species being underrepresented in the calculations.

#### 1.3.1.5 Extrapolation to all stations

Many of the stations in the US have never had their impingement or entrainment studied. The calculations therefore have to make a series of estimates to quantify the loss of fish caused by the stations, based on the flow of each station and its location. The relationship between water use and the number of fish entrained is not simple. Not all water bodies are equally productive, and even within a single waterbody some areas have much higher numbers of fish than others. This is particularly true for eggs and larvae of fish, where many species have preferred spawning habitats. Using an estimate of the total I&E which included data that are extrapolated or interpolated for plants that lack data, although probably the only method available, does introduce considerable uncertainty.

For the reasons discussed, EPA's estimates of age 1 equivalent fish killed by power plants is unreliable and is likely an underestimate, potentially a significant underestimate, of the actual mortality numbers. It should also be noted that the age 1 equivalent metric, even when accurately estimated, fails to account for all ecological effects because it ignores species other than fish and fails to take proper account of the ecological value of forage fish as food for other organisms.

### 1.4 Conclusion

Large cooling water intakes impact the environment in many different ways. These range from directly killing fish by entrainment or impingement, to changing the food chain and adding an unnatural selective pressure on the populations present. The EPA concentrates their rulemaking on the impact on fish but the impact is not only on fish, but the full range of organisms occupying the aquatic habitat.

## 2 Required studies

Below is a list of the studies required by the proposed rule. The range of background data required is significant, and includes all the physical and operation factors that affect I&E. There are some areas of the impingement and entrainment monitoring that require further analysis which are discussed in the following two sections.

**Table 1: The list of reports required by the proposed rule.**

| | Cooling towers | > 125MGD | < 125MGD No demonstration of technology | GT 125MGD With demonstration of technology* |
|---|---|---|---|---|
| Source water physical data | y | y | y | y |
| Cooling water intake structure data | y | y | y | y |
| Source water baseline biological characterization data | y | y | y | y |
| Cooling water system data | | y | y | y |
| Proposed impingement mortality reduction plan | y | y | y | y |
| Performance studies | | y | y | y |
| Operational status | | y | y | y |
| Entrainment characterization study | | | | y |
| Comprehensive technical feasibility and cost evaluation study | | | | y |
| Benefits valuation study | | | | y |
| Non-water quality impacts assessment | | | | y |

*Facilities withdrawing more than 125 MGD (except those with closed cycle), and existing facilities with new units that plan to demonstrate performance equivalent to closed cycle.

In Section 122.21(r)(7) it is envisaged that if the performance studies relied on are over 10 years old that the study would have to be repeated or explained as to why that is not necessary – it does not say whether this should occur every 10 year, to account for any further changes.

## 2.1 *Impingement monitoring requirements*

Within the impingement monitoring requirements, one of the areas of most concern is the measurement and quantification of survival after impingement. It is proposed to allow stations to operate where impingement mortality is less than 12% annually, and 31% in any one month.

The rule is not specific on the level of effort required to assess impingement. It suggests one weekly sample during primary periods of impingement, and no less than biweekly at all other times of year, with all samples collected over 24 hours.

The rule is unclear as to how long a fish must survive to be counted as alive – it suggests 24 – 48 hrs. It does not say how impinged fish should be chosen for the impingement survival study. Is it all fish impinged – which would require very large holding tanks - or it is only selected fish? If it is selected fish, the temptation to choose healthy-looking fish would be strong.

Fish would be taken from the fish return system prior to release to the environment. The final stage of the fish return system is often not well-designed for fish health. For example the fish return system may drop the fish back into the sea from an appreciable height, and into the jaws of a seagull.

There is no requirement to analyse the full size range of fish impinged – there may be significant differences in survival between young and old fish.

The rule also allows the exclusion of some fish species as aliens, or naturally moribund. The list of species to be monitored will be set by the director. It will include threatened or endangered species, but does not state that it must include any particular species. Studies should include all species that make up, for instance, 95% of the impinged fish by weight or number.

If the station used a finer mesh than the standard 3/8" inch, the facility only has to measure impingement mortality for the proportion of the catch that would have passed through the 3/8" mesh. This is problematical – there is not a distinct cut-off for the size of animal that will pass through a 3/8"inch mesh. It depends on many factors, such as body shape of a particular species (long thin forms can pass through the mesh when many times longer than 3/8"), the angle at which a fish approaches the mesh (head on, most fish are smaller than side on), the amount of debris already on the mesh, and the number of times an animal may be impinged and washed off before being lifted into the trash/fish handling system. It is not clear how any of these variables will be taken into account.

If a station has flows below 0.5ft/s they are required to monitor the flow no less than twice a week, but not monitor the impingement.

## *2.2 Entrainment monitoring requirements*

The EPA has defined AIF as the average volume of water withdrawals on an annual basis over the past three calendar years. This is the flow measure used to assess entrainment.

For the purpose of the rule, any organism that passes through a 3⁄8 inch sieve is defined as entrainable. This is again problematic, as commented on above. The density of organisms in front of the station intake is measured and entrainment estimated from that.

Samples would be collected at a minimum recommended level to monitor the species of concern, as requested by the director. Sampling would be no less than biweekly during the peak abundance identified during the source water baseline characterization.

100% mortality is assumed unless there are survival studies in place to demonstrate otherwise.

## *2.3 Timing*

The numerous studies required for the rule have a long timescale to completion – an 8-year timescale for impingement and a 10-15 year timescale for entrainment. This seems to be a long time to enforce higher standards of environmental management.

## *2.4 Entrainment mortality/survival monitoring*

It has generally been accepted that the only safe assumption for the mortality of fish entrained in the cooling water flow is 100%. This is the view expressed by the EPA in the regulations; we support that view and present our reasons for believing that 100% mortality is the only reasonable assumption. (Table 3.18. EPA Environmental and Economic Benefits Analysis for Proposed Section 316(b) Existing Facilities Rule EPA 821-R-11-002 March 28, 2011).

Some entrainment survival is proposed to be allowed, if supported by suitable studies. The causality of entrainment mortality is discussed below.

Entrainment is the passage of aquatic organisms through the cooling water system of a power station. The size of the animal entrained depends on the mesh size of the screens used to filter the water. Animals that are small enough to pass through the screens are carried through the cooling water system. Of the wide range of planktonic organisms and early life stages that are entrained, the animals that are usually studied are small crustaceans and fish eggs, larvae and young.

During the passage through the CW circuit, organisms undergo a range of stresses that often lead to injury or mortality. The principle causes of harm can be classified into (1) mechanical (abrasion, pressure), (2) thermal (elevated water temperature and rapid changes in temperature) and (3) chemical (addition of biocides).

Factors that affect entrainment rates include:

- CW intake location in relation to spawning grounds
- Life history of species
- Habitat preferences of species
- Swimming ability
- Growth rates and morphology

Entrained organisms, while passing through a power station, suffer a combination of impacts.

- Mechanical stress of contact with the walls of the cooling water (CW) system, pumps and any biofouling present.
- A series of rapid pressure changes as the water passes through the screens, pumps and condensers.
- Shear stress of water as it is accelerated and decelerated.
- Chemical stress, if the organism is exposed to the biocides used to control fouling.
- Thermal stress as the water is rapidly warmed by around 10°C in the condensers.

### 2.4.1 Survival tests for entrained animals

Survival tests have shown that larval fish that have experienced passage through a power plant cooling water system suffer increased levels of mortality. The increased mortality is evident over all time periods studied, and fish still show an excess mortality over controls, even many days after entrainment.

Mortality is calculated by studying larvae from before (control) and after entrainment (experimental). The two samples are observed at intervals, often immediately and at 24, 48, 72 and 96 hours, and the number remaining alive in each sample noted. The mortality that is attributed to the entrainment is the difference in the number alive in the experimental and control sample. Performing these experiments is difficult and has many problems, not least because larval fish are extremely delicate.

The collection and handling of these very young fish is a difficult task. The stress of handling the fish can often lead to significant mortality, even in the control populations. This can lead to a masking of any entrainment effects, when the survival rate is lower in the control population than in the entrained fish. In the most extreme example, 100% mortality of the control sample leaves no mortality that can be attributed to the entrainment; combined with 100% mortality of the experimental sample it could even be taken to imply 100% survival. Control samples with 100% mortality occur at several sites, for example from chapter 7 of the § 316(b) Existing Facilities Benefits Case Studies, Part A: Evaluation Methods:

*"In many studies, the survival in the intake sample is extremely low, for example the intake survival for bay anchovy was zero percent in studies conducted at Bowline (Ecological Analysts Inc., 1978), Brayton Point (Lawler, Matusky & Skelly Engineers, 1999), and Indian Point (Ecological Analysts Inc., 1978 and 1989)."*

However even a more modest mortality level in the control population will mask the true effect of entrainment. If, for example, 50% of the larvae in a control sample were so delicate that they died as a result of the handling procedure, they presumably would also be killed by entrainment. However there is no means of separating the two mortality effects and it can lead to an underestimation of entrainment mortality.

A further bias occurs with the instant mortality rate, as many studies count stunned fish as alive. Longer-term studies revealed that the majority of the fish classed as stunned died.

The samples taken are often not representative of the community of organisms entrained as some species will be under-represented, and others over-represented. This can be due to a variety of factors, including the behaviour of the animals and the pattern of flow through the plant. Some species are extremely fragile and will disintegrate during collection or preservation, and are thus not documented when samples are processed (Boreman and Goodyear 1981).
Boreman and Goodyear (1981) showed that delicate organisms could easily be damaged beyond identification. This leads to an over-estimation of survival as these fish are not counted.

 

Problems with the selection of dead and dying animals also lead to over-estimations of survival. Marcy (1975) showed that healthy specimens are sampled in preference to dead organisms, particularly if the dead organisms tend to settle out of the water.

Mortality of both control and experimental samples increases over time. In other words, fish can take many days to die from the effects of entrainment. Most studies only present the immediate and 48 hour survival times, whereas the effect on larvae might be apparent over a much longer period than this. No experiment has ever shown exposed fish to recover to a mortality rate as low as the controls.

Beyond immediate survival, the effect of entrainment needs to be accounted for on the release of the fish back into the environment. The predation pressure on young fish is very high. Fish returned to the water body after entrainment, even if they are alive, are likely to suffer much higher predation rates than individuals that have not been entrained. It is well-established that injured or disorientated larval and young fish are highly vulnerable to predators. It is therefore likely that many entrained organisms that have survived passage will be eaten. Because returning entrained organisms are easy to catch, there is often a concentration of predators at the outfall that will increase the mortality still further. Increased likelihood of predation can occur for a number of reasons, including:

- Position in the water column. Many species have developed vertical migration patterns within the water column to reduce the predation. On returning to the water body via the outfall of a facility they are unlikely to be in their favoured part of the water column and hence will be more vulnerable to predation.
- Behavioural disturbances. The ability of larval fish to behave normally after entrainment is under-studied. However those studies review by Schubel et al, (1978) found a range of behavioral differences. These included erratic swimming, convulsions, disorientation and jumping.
- Physical effects. It was noted that the response to a rapid cooling, as experienced by a fish returning to its water body after entrainment, is often more severe than the one caused by the initial temperature increase.

It has been shown that thermal shock can disrupt development of eggs and larvae in fish even if they survive entrainment (Schubel et al, 1978). Long term sub-lethal damage is difficult to observe in larval fish.

There is good evidence that any growth check during the early stages of a young fish's life can results in subsequent poor growth and an inability to compete effectively. Many fish that suffer in early life do not survive their first winter, as they have been unable to grow and lay down sufficient fat reserves.

In the most experiment, the fish are reared under carefully-controlled laboratory conditions. In the real world the larval fish and eggs are released back into a natural water body. Natural waters generally have very high levels of bacteria and viruses present, and any slight damage to a larval fish will make it highly susceptible to disease. Eggs' main protection from disease is the integrity of the egg membrane, which is likely to be damaged during entrainment. Larval fish have almost no antibody defence against disease and any small breach of the skin is likely to become infected.

All these factors make any assessment of survival difficult even when undertaken at a site. There is always considerable uncertainty in the estimate of any survival found in site specific studies.

## *2.5 Impingement mortality/survival monitoring*

Impingement is a term used to describe the fate of larger fish and crustaceans that are retained on the fine filter screens by the force of water passing through the intake system, and then are washed off into some kind of collecting trough or hopper. Impinged fish are often harmed by their contact with the filter screens, and are either killed or returned, possibly injured, to the environment.

The rate of impingement in all habitats increases with the volume of water extracted. Further, for a variety of reasons linked in part to fish behaviour, larger intakes can catch considerably more fish than would be predicted by using the catch per unit volume observed at smaller intakes. For large intakes the several factors combine to make it more difficult for fish to avoid impingement. Firstly, it may be difficult for a fish to "know" it is being impinged. If the pipe running to the station is 15ft in diameter a fish in the centre of the pipe is 7.5ft from either wall – this may be beyond it senses, either due to low light, turbidity or turbulence. Further even if it does know it is being impinged it had to swim several yards against a current to escape. This requires it to understand in which direction safety lies. From the centre of the flow this might not be obvious to a fish. Indeed many fish dive for cover when threatened and may well seek shelter in the darker intake pipe. With a small pipe the situation is different, as the fish has a higher chance of seeing it, and a much higher chance of escaping it.

The survival of fish after impingement is a much studied subject. There are many designs for impingement mortality/ survivorship that have been reviewed by the EPA (for example 316(b) Phase II Final Rule – TDD Efficacy of Cooling Water Intake Structure Technologies 2004). Many studies have problems that make their general applicability difficult.

One of the areas of greatest contention is how long to keep fish after impingement to give a good estimate for survival. The EPA is suggesting either 24 or 48 Hours. These are probably too short.

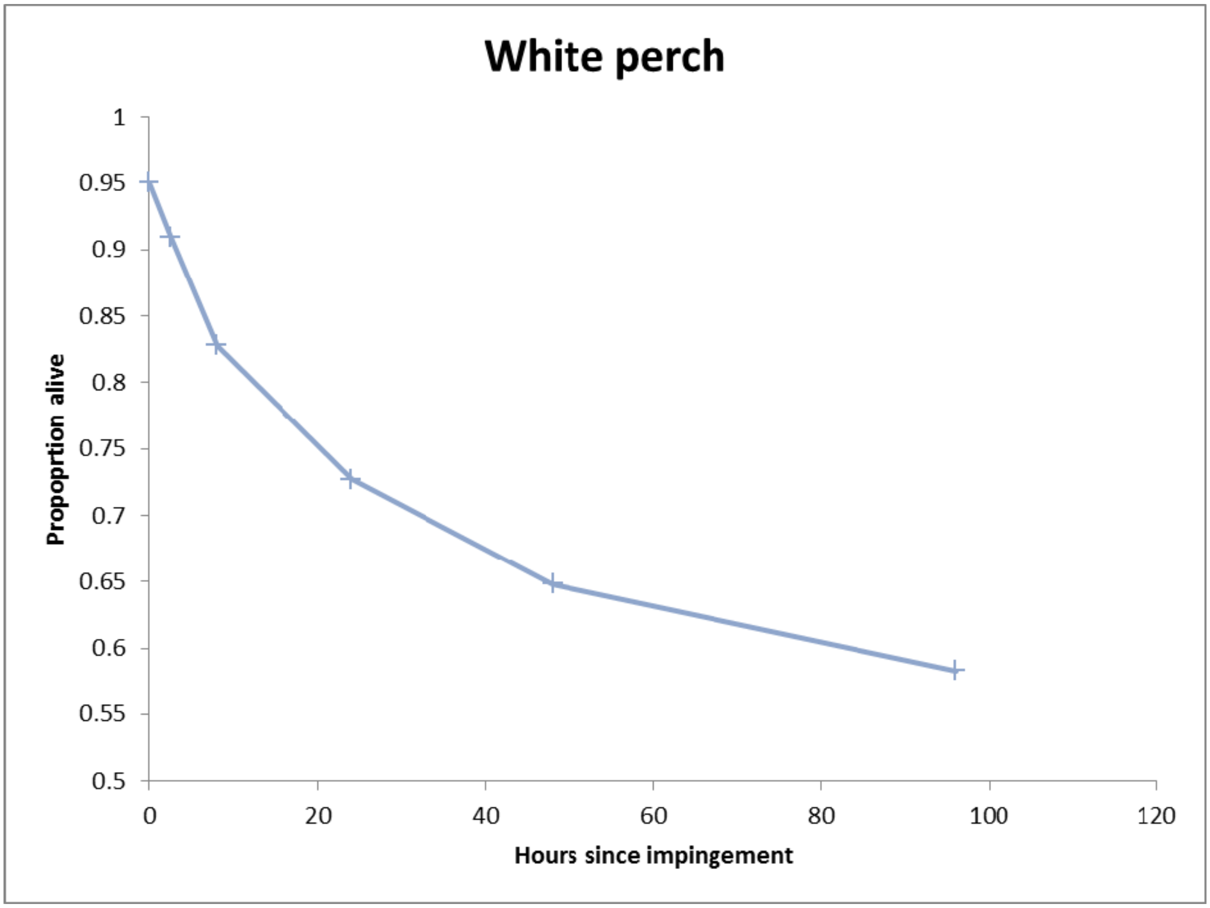


**Figure 1: Proportion of white perch surviving at Roseton. Data from Table 3 (NAI 1995)**

Even for species which are quite robust, such as white perch the time taken to die can be quite long (Figure 1). After 24 hours some 73% are alive after 48 hours this has fallen to 65% and after 96 hours it has reached only 58% and still appears to be declining. In fact, survival monitoring should take place over an entire year because different environmental and biological conditions can have a striking impact on survival.

If the fish is already near it temperature limits, or is stressed by low oxygen then it is more likely to die than an unstressed fish. Fish may also experience added stress just before, or right after breeding. These fish have less energy and are more susceptible to the impacts of cooling water intake structures.

To ensure the 12% impingement mortality restriction contained in EPA's proposal is met, the rule must also require a demonstration that 88% of fish survive entrainment up to a certain point after impingement. Determining that point in time is crucial to meeting this restriction and existing studies like the one at Roseton demonstrate that 24-48 hours is not enough time to allow some of the injured fish to die.

# 3 Impingement controls

## 3.1 Introduction

The proposed rule gives plant operators the choice between reducing intake velocity to 0.5 feet per second (fps) or reducing their impingement mortality to less than 12% annually and 31% in any one month of the total number of fish impinged. In addition, the proposed rule: (a) requires plants that presently have travelling screens to add protective measures to those screens; (b) requires all plants to ensure that entrapped fish have a means of escape back to the waterbody; and (c) requires plants on ocean or tidal waters to reduce shellfish mortality to a level consistent with the performance of properly deployed and maintained barrier nets. A comparison of the two potential primary standards and the additional standards is provided below following a discussion of the efficacy of technologies commonly used to reduce impingement and impingement mortality.

## 3.2 A standard intake configuration

A standard cooling water intake is equipped solely with conventional travelling screens designed to prevent debris and adult and juvenile fish from entering the condenser tubes. Such intakes typically have trash racks usually consisting of fixed bars to prevent large debris from entering the system, and drum or band screens, usually with 1 cm mesh, that prevent smaller debris from clogging the condenser tubes. The screens are rotated and washed intermittently at a typical pressure of $5.5 \times 10^5$ $Nm^{-3}$ to $8.4 \times 10^5$ $Nm^{-3}$. The debris and fish are often collected in trash baskets. No fish are returned to the water and all die. In the proposed rule all the intakes with travelling screens will be required to have fish return systems.

## 3.3 Reducing impingement by reducing intake flow (volume) and velocity

Several approaches and technologies are available to prevent impingement by reducing the volume and/or velocity of the cooling water withdrawn by an intake.

### 3.3.1 Cooling towers

As EPA states in its proposed rule, “Flow reduction is the clearest way to reduce I&E, as lower intake flows will impinge and entrain fewer organisms, generally in proportion to the amount of flow reduction” (316(b) Existing Facilities Proposed Rule - TDD Chapter 6: Technologies and Control Measures, March 2011).

A dry cooling system will achieve an average reduction in cooling water intake flow greater than 99 percent over a once-through system. In comparison, the average flow reduction of a closed-cycle wet cooling system for an estuarine/tidal source is around 94.9 percent, and around 97.5 percent for a freshwater source (316(b) Existing Facilities Proposed Rule - TDD Chapter 6: Technologies and Control Measures, March 2011). The EPA estimates that the reduction in impingement mortality that this would achieve would be 97.5% in freshwaters and 94.9% in saline waters. With such reductions in flow, wedgewire screens become feasible, which can reduce the impingement to zero.

While dry cooling effectively eliminates aquatic impacts, a substantial level of protection of aquatic organisms can be achieved using wet or hybrid cooling particularly when protective technologies are fitted to the intakes.

### 3.3.2 Intake velocity restriction

Reducing the velocity of the water entering an intake will generally reduce the level of impingement. The EPA has studied this subject and has come to the opinion that 0.5 feet per second (fps) is protective in terms of fish impingement, and is in fact in place at the majority of the facilities built within the last 15 years. The EPA indicates that a 0.5 fps through-screen velocity would be protective of 96% of species. This level allows for some of the intake to clog, while keeping the velocity at a level that is protective to fish. This suggested level of protection is discussed below.

### 3.3.3 Fish Escape

Reducing the velocity of the intake to protect fish requires the velocity to be low at the first point at which a fish may react to the intake. This allows the fish time and space to avoid the intake. The realised effectiveness of a low velocity intake will be affected by several factors including;

- The swimming ability of the species present.
- The size range of the fish present.
- The behaviour of the species present.
- The detectability of the intake to fish
- The environment in which the intake is sited

Fish swimming ability varies considerably between species. Some species can maintain high speed for long periods before exhaustion; others can only swim in brief bursts. Generally, for fish of the same species, larger individuals can swim faster than small ones. However, even larger fish that are strong swimmers are frequently impinged, indicating that swimming ability is not the only factor determining the rate of impingement.

The behaviour of fish species also varies greatly, with some species actively searching out crevices, where as others try to spend their entire life in open water and avoid surfaces. If a fish is actively looking for shelter, just because it can escape from an intake, does not mean it will try, and once it is within the system it may no longer be able to escape. Other individuals many simply not “understand” that an intake should be avoided. Finally, the environment around an intake can affect the ability of a fish to detect its presence. For example highly turbid or turbulent water may mask the presence of the intake to a fish.

It should always be remembered that large fish which almost certainly did have the power to escape are frequently caught on screens of existing power plants, indicating that swimming ability is not the only factor determining the rate of impingement.

## 3.3.4 Velocity Characteristics of Water Intakes

### *3.3.4.1 Onshore and shoreline intakes*

An onshore intake is defined as one where the water is abstracted without the need for an offshore pipeline and intake structure. Where the marginal water is shallow, water is normally taken via a deep canal, or directly through a sea wall or river bank where the marginal water is deep. The second type is known as a 'shoreline' intake.

A typical onshore intake layout is shown below.

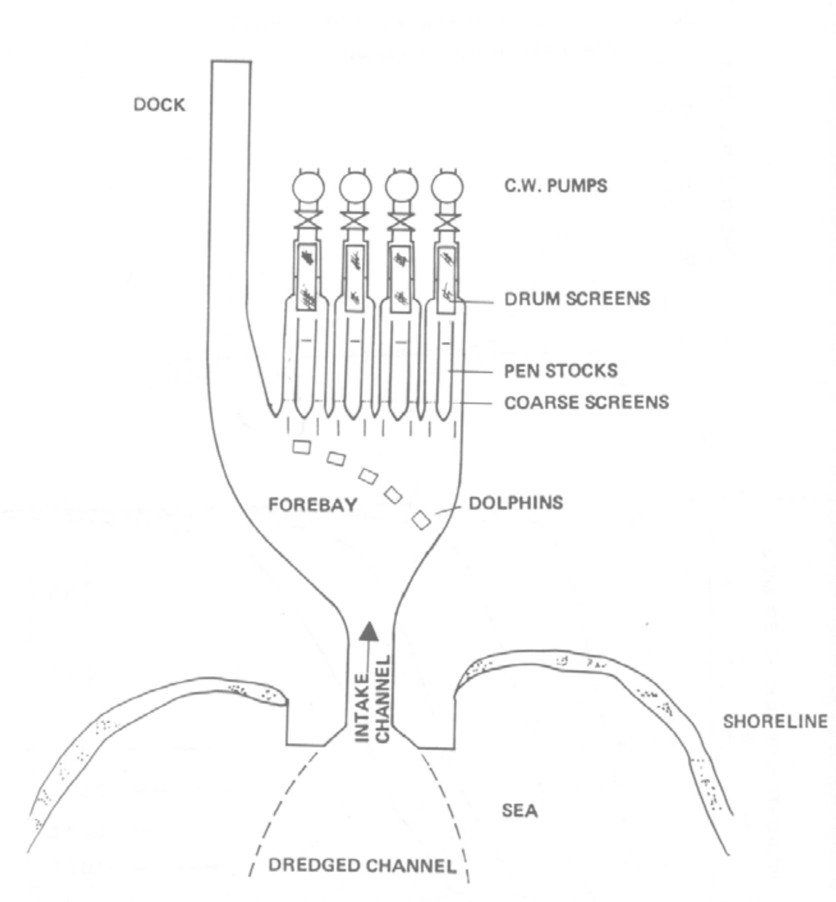


**Figure 2: An example of an onshore canal intake**

Water enters via an orifice in a vertical wall. The opening is normally protected by a coarse screen or 'trash rack' of vertical steel bars fixed at circa 15 cm centres. Beyond this is a travelling band or drum screen which removes entrained fish and debris. While it has been shown that live fish released behind the coarse screens into the screenwell area can escape from the system, the hazards of turbulence in the screenwells and of sometimes toxicity due to chlorine injected to prevent bio-fouling render this opportunity unlikely as a general rule. The design expectation should therefore be that fish are enabled to escape before passing through the coarse screens.

The vertical openings of onshore intake designs lend themselves to fish escape since the water currents are predominantly horizontal at the coarse screens. The main consideration for fish escape is therefore that the approach velocity at that point, under all operating conditions, is kept within the swimming speed ranges of the fish. It is preferable that a uniform velocity profile be achieved across the face of the screens but, if not, that the conditions for fish escape are met at the maximum velocity value.

A difficulty of some canalized onshore intake designs is that the point of maximum approach velocity in the canal is at some distance ahead of the coarse screens and not at the screen face. As a consequence, by the time fish come into contact with the coarse screens and attempt to escape, poorer swimmers become trapped within the system.

A further aspect of great importance is that in tidal waters fish move off the mudflats as the tide drops. To do this they follow the current. If they are in the vicinity of an intake they will follow the water into the intake. Thus their normal behaviour can cause them to move into danger.

#### *3.3.4.2 Offshore intakes*

Offshore intakes vary widely in design, but generally comprise an offshore structure connected by a sub-sea tunnel to the shoreline. Older designs, are open-topped and have strong vertical draw-down currents, whereas more recent designs have capped intakes with a more horizontal flow pattern (see below). Capped intakes may reduce fish ingress but blocking the top of an intake without considering the flow velocity and pattern is not sufficient to guarantee fish protection. There are, however, reasons unrelated to fish protection for adopting capped intake designs such as capped intakes have superior characteristics for selective withdrawal of cooler water in thermally stratified.

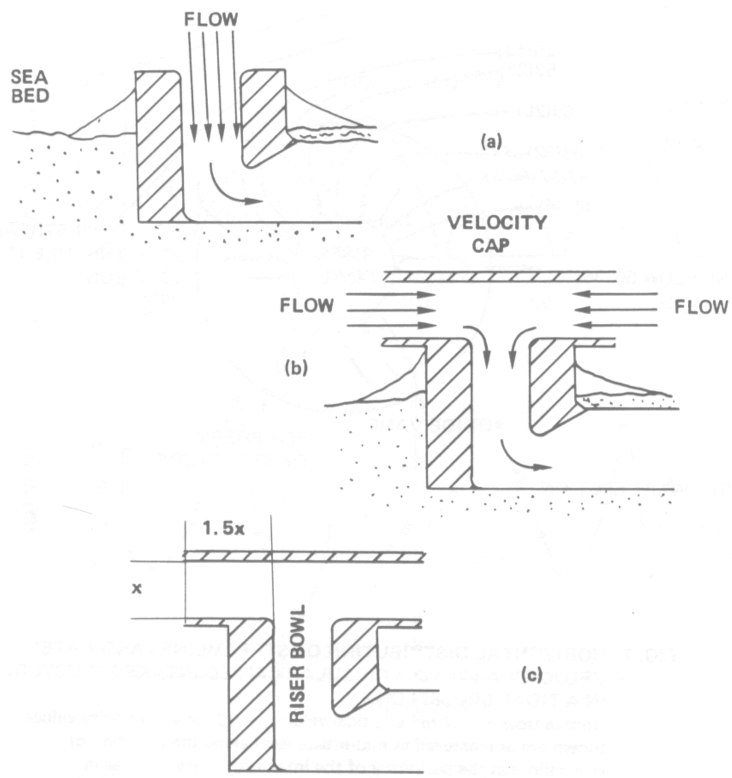


**Figure 3 A Velocity cap. (a) Section of uncapped intake showing vertical draw-down pattern, (b) section of velocity capped intake showing horizontal flow pattern, (c) as (b) but showing critical relationship between vertical opening (x) and length of horizontal entrance (1.5x) for fish reactions. Intake grills omitted. (After Schuler and Larson, 1975)**

The horizontal flow pattern around an offshore structure is just as important as it is for onshore intakes. In still water, inflow is uniform around the structure and streamlines are normal to the trash-rack bars. In a tidal cross-flow, the distribution becomes biased, with most of the water entering close to the upstream radial axis where the approach velocity is consequently higher (see below).

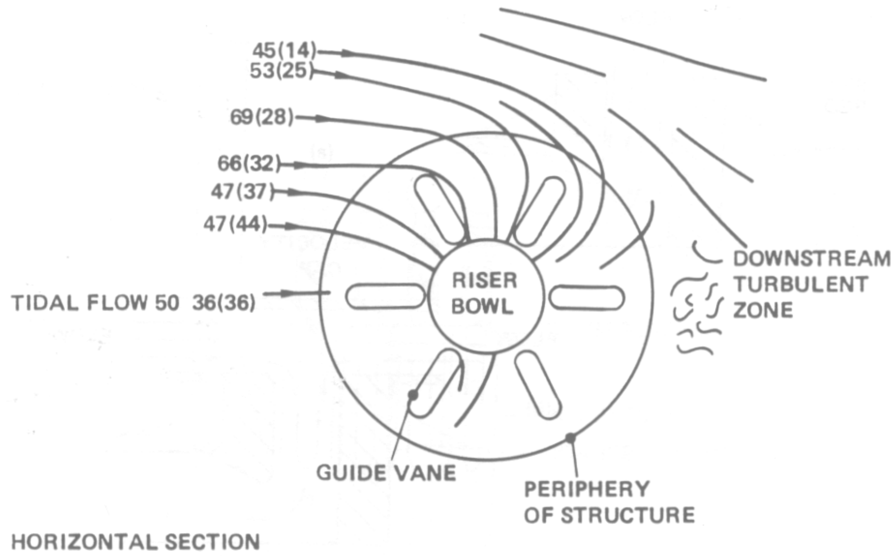


**Figure 4: Horizontal distribution of streamlines and water velocity around a circular capped intake structure in a tidal crossflow. Intake flow - 13.7 m$^3$ s$^{-1}$, tidal velocity of 50 cm s$^{-1}$, velocity values shown are as measured at mid-intake level along the direction of streamlines at the periphery of the intake structure. Values in parentheses are vectors normal to the periphery. All values are in units of cm s$^{-1}$. [Based on trials with a 1/50 scale model]**

The catch rate at an offshore structure sited in a tidal stream is maximal around mid-flood and mid-ebb, and minimal around the slack water period. This has indeed been shown to be the case.

In hydraulic model tests carried out at CERL using a capped, circular intake with a nominal approach velocity (flow/screen area) of 25 cm s$^{-1}$, the measured peak velocity in a simulated 50 cm s$^{-1}$ tidal crossflow was 70 cm s$^{-1}$. As a principle, it is not possible to achieve maximum approach velocities of less than the tidal cross-flow velocity using a circular intake structure.

The above point has great importance, for it effectively states that irrespective of the velocity that would be generated in still water, in flowing water an offshore intake will have a maximum approach velocity determined by the tidal velocity. As the tidal velocity is frequently greater than the sustainable swimming speed of fish this means that they will be vulnerable to capture **no matter how low the nominal intake velocity is**.

### 3.3.5 Variable speed pumps

In a power station cooling water system, pumps are used to draw water in through the intake and circulate it through the plant’s cooling system. A single speed pump generates the maximum designed flow whenever it is operating. It is either on or off. Pumps can, however, be designed to operate at variable speeds so that when set on a lower speed they withdraw less water from the source water body. Using a variable speed pump within a power plant cooling system would enable the facility operator to reduce flow whenever conditions such as low inlet temperatures and/or low demand dictate that a reduced flow will provide adequate cooling for the amount of electricity generated. In other words, variable-speed pumps give a plant operator the ability to tailor cooling water withdrawals to the minimum amount actually needed for cooling. Thus, the use of variable speed pumps could allow a reduction in flow for a once-through cooling system at times when higher flows are not needed.

Variable speed pumps do not provide a constant impingement reduction benefit. They provide a benefit only when the plant is actually able to reduce flows and still generate electricity and meet thermal discharge limitations. Because of the variability in inlet water temperatures and electricity demand, it is difficult to reliably predict the effectiveness of this option for reducing flow (and impingement) on an annualised basis.

## *3.4 Other methods of reducing impingement or impingement mortality*

If it is the number of fish being impinged cannot be reduced by reducing the volume extracted, other methods of reducing impingement or impingement mortality can be used.

### 3.4.1 Modified travelling screens with fish return - Ristroph screens

The simplest modification to normal conditions is to run the screens continuously and use a fish return sluice to return impinged fish to the water. Studies reported by Muessig *et al.* (1988) undertaken at Danskammer, Bowline Point and Roseton on the Hudson river showed that 84-108 hour survival was highest for Atlantic tomcod, striped bass and white perch at about 50-90%, and lowest for bay anchovy, alewife and blueback herring at 0 – 25 %. Other species such as pipefish and centrarchids (sunfishes) had survival rates between these extremes. These same general features indicating large differences between fish families were also recorded in studies of the fish return system at Sizewell nuclear power station on the English east coast, where 24-hour survivals were from about 100% for flatfish such as flounder and plaice, 40 to 90% for cod, bass and whiting, to 0% for Atlantic herring and sprat. These studies and others indicate that fish return systems fitted to unmodified screens will not aid the survival of herring family (clupeid) fish to any appreciable extent.

Ristroph screens have water-filled lifting buckets which collect the impinged organisms and transport them to a fish return system. The buckets are designed to hold approximately 2 inches of water when raised. The buckets hold the fish in water until the screen rises to a point where the fish are spilled onto a bypass, trough, or other protected area (Mussalli, Taft, and Hoffman, 1978). Fish baskets are another modification and may be used in conjunction with fish buckets. Fish baskets are separate framed screen panels that are attached to vertical travelling screens. Modified travelling screens can operate continuously as compared to traditional traveling screens that often only operate intermittently. Conventional travelling screens typically operate on an intermittent basis. Impinged fish are usually returned to the source water body by sluiceway or pipeline.

It is inevitable that fish will try to avoid capture in the lifting buckets, and will have a high risk of coming into contact with hard surfaces. This will result in exhaustion and damage to their skin, fins and eyes which can be sufficiently severe to lead to the mortality of the more fragile species. The degree of mortality will depend on the species and the particular life stage, plus numerous physical factors including water temperature, oxygen concentration and salinity. It is generally the case that pelagic (open water) species, which are poorly adapted for contact with hard surfaces, are particularly vulnerable to surface damage to their bodies. Thus it is inevitable that the reduction in impingement mortality that these screens can produce when compared to a conventional travelling screen standard is variable and highly species-specific.

To determine overall performance requires information on species-specific mortality rates and the species composition of the impinged community. Ideally we would require data on the temporal variation in both the fish community composition and mortality rates, but, as these are unavailable, a degree of uncertainty must remain.

A key aspect to consider when analysing fish survival data from Ristroph screens is the time after impingement and handling when survival was measured. Some early studies quoted high survival after 10 to 15 minutes in a holding tank. This is clearly of little interest, as most acutely injured fish will take considerably longer to die.

The minimum time at which survival rates are likely to give a true indication of the eventual survival of the impinged fish will be after about 8 hours, and Fletcher (1990) gives estimates for the survival of common species at Indian Point in the Hudson River estuary after this time period (Table 2).

**Table 2. Eight-hour survival rates for Indian Point (Fletcher, 1990)**

| Fish species | Survival % |
|---|---|
| **Bay anchovy** | 77 |
| **American shad** | 65 |
| **Blueback herring** | 74 |
| **Striped bass** | 91 |
| **White perch** | 86 |
| **Atlantic tomcod** | 83 |
| **Alewife** | 38 |

The Kintigh Generating Station in New York has recorded survivals of generally greater than 80 percent for rainbow smelt, rock bass, spottail shiner, white bass, white perch, and yellow perch.

Gizzard shad survivals have been 54 to 65 percent and alewife survivals have been 15 to 44 percent.

It should be noted that there are a number of factors that will probably reduce further the survival of fish. First, survival over an extended period will be lower than the 8-hour survival. Stressed and damaged fish can take a number of days to die. Experiences in angling and fish farming demonstrate that minor damage may lead to bacterial and fungal infections resulting in eventual death[1]. There is also the problem with all fish return systems that exhausted, disorientated and damaged individuals can fall prey to predators on their return to the main water body. It is normal to observe large predatory fish and piscivorous birds waiting and feeding at water discharges.

The progressive decline in survival with time following impingement is demonstrated with data collected at Roseton Generating Station in the Hudson River estuary (Table 3). Apart from spottail shiner, all other species showed a marked decline in the rate of survival between 2.5 and 96 hours after impingement. This clearly indicates the need to use survival estimates over periods of at least 96 hrs if the post-impingement survival is to be correctly estimated.

**Table 3: Data from 1994 impingement mortality studies at Roseton (dualflow screens) (NAI 1995).**

| Species | Number | Survival rate through time | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 hr | 2.5 hr | 8 hr | 24 hr | 48 hr | 96 hr |
| American shad | 575 | 0.689 | 0.252 | 0.123 | 0.080 | 0.071 | 0.068 |
| Alewife | 1839 | 0.662 | 0.229 | 0.151 | 0.096 | 0.073 | 0.060 |
| Bay anchovy | 1093 | 0.282 | 0.169 | 0.110 | 0.032 | 0.014 | 0.004 |
| Blueback herring | 8973 | 0.753 | 0.335 | 0.204 | 0.110 | 0.090 | 0.071 |
| Striped bass | 899 | 0.889 | 0.740 | 0.578 | 0.494 | 0.405 | 0.345 |
| Spottail shiner | 331 | 0.958 | 0.931 | 0.915 | 0.897 | 0.873 | 0.831 |
| White perch | 899 | 0.950 | 0.909 | 0.828 | 0.727 | 0.648 | 0.583 |

The difference in survival between Table 2 and Table 3, for example bay anchovy (77 to 11%), is an indication of how much survival can vary between different intake systems. Design of screens, intake velocities and wash water systems can all make a difference in the survival of impinged fish.

Second, temperature and salinity can have a great effect upon survival. Injured fish are far more likely to die at low temperatures and at low salinities. Salinity is probably important because damage to the skin results in a loss of osmotic control. The effect of both these variables is demonstrated by the work of Muessig *et al.* 1988 (See Figure 5). While these studies were carried out on conventional, not Ristroph, screens they still give insight into the effects of salinity and temperature upon injured individuals.

[1] E.g. Tournament-associated Mortality in Black Bass - Gene R. Wilde - Fisheries 1998; 23: 12-22

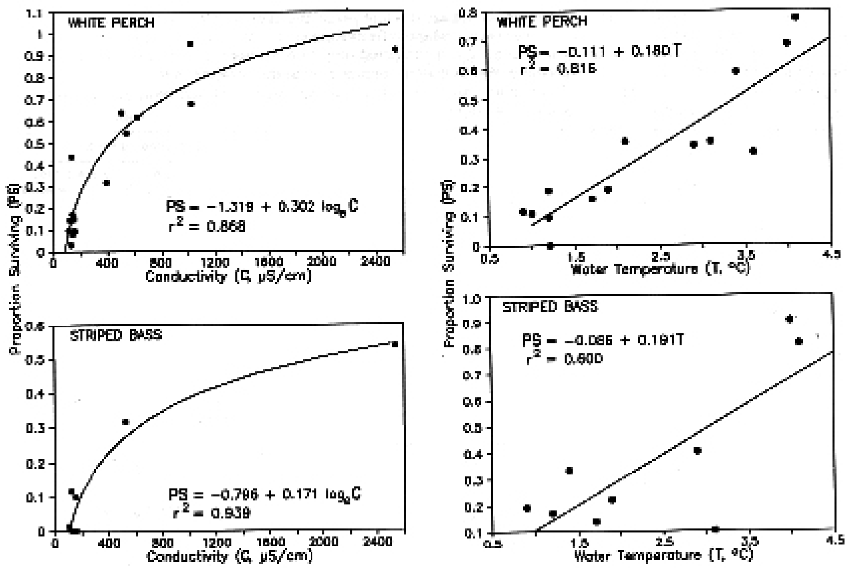


FIGURE 66.—Extended survival of impinged white perch and striped bass related to specific conductance, for temperatures above 4.5°C.

FIGURE 67.—Extended survival of impinged white perch and striped bass related to water temperature, for water temperatures less than 4.5°C.

**Figure 5: The survival of white perch in relation to water temperature and salinity following impingement. Reproduced from Muessig *et al.* (1988).**

The above considerations indicate that clupeid fish such as the sprat and herring are more vulnerable to damage than fish belonging to other families. Further, short-term survival rates at intermediate water temperatures and salinities are unlikely to fully reflect the eventual mortality rate for species that are easily injured.

The above considerations suggest that the post-impingement survival rates presented in the PSEG Power New York Inc's *Bethlehem Energy Center SPDES Modification, Alternative Cooling Systems Study for Ristroph screens* and presented in Table 4 give a fair appraisal of survival for American east coast estuarine and marine fish. Further, these values can provide survival estimates for fish families that can be used to make general estimates of post-impingement survival on Ristroph screens for species for which no data exist.

**Table 4. The post-impingement survival of fish on conventional and Ristroph screens. From PSEG Power New York Inc's Bethlehem Energy Center SPDES Modification, Alternative Cooling Systems Study.**

| Family | Species | Percent Survival | | Family | Species | Percent Survival | |
|---|---|---|---|---|---|---|---|
| | | Conventional | Ristroph type | | | Conventional | Ristroph type |
| Acipenseridae | Atlantic sturgeon | 60 | 80 | Cyprinodontidae | Banded killifish | 85 | 90 |
| | Shortnose sturgeon | 60 | 80 | | Mummichog | 85 | 90 |
| Anguillidae | American eel | 70 | 95 | Engraulidae | Bay anchovy | 0 | 80 |
| Bothidae | Summer flounder | 70 | 95 | Esocidae | Chain pickerel | 70 | 90 |
| Catostomidae | White sucker | 50 | 70 | | Northern pike | 70 | 90 |
| Centrarchidae | Black crappie | 30 | 40 | | Redfin pickerel | 70 | 90 |
| | Bluegill | 80 | 80 | Gadidae | Atlantic tomcod | 10 | 70 |
| | Largemouth bass | 75 | 90 | Gasterosteidae | Fourspine stickleback | 70 | 90 |
| | Longear sunfish | 70 | 80 | | Threespine stickleback | 70 | 90 |
| | Pumpkinseed | 75 | 80 | Ictaluridae | Brown bullhead | 65 | 90 |
| | Redbreast sunfish | 70 | 80 | | Channel catfish | 70 | 90 |
| | Rock bass | 70 | 80 | | Tadpole madtom | 70 | 90 |
| | Smallmouth bass | 75 | 90 | | White catfish | 75 | 90 |
| | White crappie | 30 | 40 | | Yellow bullhead | 70 | 90 |
| Clupeidae | Alewife | 0 | 10 | Osmeridae | Rainbow smelt | 0 | 85 |
| | American shad | 0 | 10 | Percichthyidae | Striped bass | 25 | 70 |
| | Blueback herring | 0 | 10 | | White bass | 25 | 70 |
| | Gizzard shad | 5 | 10 | | White perch | 25 | 70 |
| Cyprinidae | Bluntnose minnow | 50 | 90 | Percicidae | Logperch | 65 | 80 |
| | Carp | 50 | 80 | | Tessellated darter | 90 | 100 |
| | Common shiner | 50 | 90 | | Walleye | 65 | 80 |
| | Creek chub | 50 | 90 | | Yellow perch | 65 | 80 |
| | Emerald shiner | 50 | 90 | Percopsidae | Trout-perch | 15 | 20 |
| | Fallfish | 50 | 90 | Petromyzontidae | Lamprey spp. | 70 | 95 |
| | Golden shiner | 45 | 90 | Salmonidae | Brown trout | 60 | 80 |
| | Goldfish | 50 | 80 | Sciaenidae | Freshwater drum | 20 | 25 |
| | Rosyface shiner | 50 | 90 | Soleidae | Hogchoker | 90 | 95 |
| | Silvery minnow | 50 | 90 | Umbridae | Central mudminnow | 60 | 80 |
| | Spotfin shiner | 50 | 90 | | | | |
| | Unidentified shiner | 50 | 90 | | | | |

EPRI summarized the finding by family for American species in the following table which gives some idea of survival. These are obviously estimated numbers and should only be used as an approximation of survival. The values should be treated with caution, as many factors go toward determining the survival of a fish at any particular locality.

**Table 5. Electric Power Research Institute (EPRI) estimates of survival for families of American fish and invertebrates.**[2]

| | |
|---|---|
| ***High survival rate potential (71-100 percent)*** | |
| Percopsidae - trout-perches | *Cottidae - sculpins* |
| Homaridae - lobster | *Labridae - wrasses* |
| Fundulidae - killifishes | *Percidae - perches* |
| Ophidiidae - cusk eels and brotulas | *Portunidae - portunid crabs* |
| Cyprinodontidae - pupfishes | *Ictaluridae - freshwater catfishes* |
| Inachidae - spider crabs | *Cyprinidae - minnows and carps* |
| Catostomidae - suckers | *Mugilidae - mullets* |
| Bothidae - lefteye flounders | *Syngnathidae - pipefishes and seahorses* |
| Gasterosteidae - sticklebacks | *Xanthidae - mud crabs and stone crabs* |
| Pleuronectidae - righteye flounders | *Soleidae - soles* |
| Crangonidae - sand shrimps | *Centrarchidae - sunfishes* |
| Triglidae - searobins | *Penaeidae - penaeid shrimps* |
| Rajidae - skates | *Batrachoididae - toadfishes* |
| Cancridae - rock crabs | *Scorpaenidae - scorpionfishes* |
| ***Intermediate survival rate potential (31-70 percent)*** | |
| Atherinidae - silversides | *Percichthyidae - temperate basses* |
| Pinnotheridae - pea crabs | *Salmonidae - trouts* |
| Gadidae - codfishes | *Anguillidae - freshwater eels* |
| Gobiidae - gobies | *Scombridae - mackerels and tunas* |
| Infraorder Caridea - caridea shrimp | *Embiotocidae - surfperches* |
| Sciaenidae - drums | *Cyclopteridae - lumpfishes and snailfish* |
| ***Low survival rate potential (0-30 percent)*** | |
| Osmeridae - smelts | *Pomatomidae - bluefishes* |
| Clupeidae - herrings | *Stromateidae - butterfishes* |
| Engraulidae - anchovies | *Loliginidae - squids* |
| Lutjanidae - snappers | |

### 3.4.2 Angled screens

Potential problems with angled screens include the requirement for uniform flow conditions and a fairly constant approach velocity, and the need to clear debris from the screens (Taft, undated). It is not at present possible to identify any particular type of locality where angled screens would offer the best protection against impingement.

[2] Impingement and Entrainment Survival Studies Technical Support Document. EPRI, Palo Alto, CA: 2005. 1011278.

### 3.4.3 Velocity caps

Velocity caps only work on offshore intakes that take their water from, or near, the seabed. To claim that velocity caps have been successful in minimising impingement is an exaggeration. They have been found to reduce impingement by 50 to 80% when compared with an unprotected intake[3]. However, it should be noted that this reduction is usually only observed for pelagic species. Other fish and crustaceans may still be caught in large numbers.

### 3.4.4 Porous dykes

While in theory, large porous dykes could be used to filter water so as to eliminate impingement and substantially reduce entrainment losses, they are impractical and therefore cannot be considered as a viable technology. The major problem with porous dykes comes from clogging by debris and silt, and from fouling by colonisation of fish and plant life. Back flushing, which is often used by other systems for debris removal, is not feasible at a dyke installation.

### 3.4.5 Behavioural barriers

The principal ideas that have been tried are sound, bubble and light deterrent systems. In almost all cases they have been found to be ineffective in reducing impingement and are assumed ineffective for entrainment. The one possible exception is the use of sound to deter alewife. In tests at the Pickering station in Ontario, poppers were found to be effective in reducing alewife impingement by 73 percent in 1985 and 76 percent in 1986. Testing of sound systems at the James A. Fitzpatrick station in New York showed similar results, an 85 percent reduction in alewife impingement and entrainment. At the Arthur Kill station, pilot- and full-scale, high-frequency sound tests showed comparable results for alewife to Fitzpatrick and Pickering. Impingement of gizzard shad was also three times less than without the system. No deterrence was observed for American shad or bay anchovy using the full-scale system. Bubble barriers have been tried as several sites but the results are inconclusive.

Different sites have very different results to sonic deterrent systems, for example in the UK at Hartlepool, Hinkley and Oldbury. For bubble barriers we only have one set of data, from Heysham.

**Table 6: Summary data from fish deterrent trials – percent reduction, unless marked.**

| | Sound | | | Bubble barrier |
|---|---|---|---|---|
| **Species/group** | **Hartlepool** | **Hinkley** | **Oldbury** | **Heysham** |
| Clupeid | 70% | Increase 75% | 11% | 31% |
| Whiting | 50% | | 6% | |
| Bass | | | 39% | |
| Gadoids | | Increase 35% | 14% | Increase 1% |
| Flatfish | | | | 6% |

[3] Spencer, J. F. and J. M. Fleming (1987). A comparison of the cooling water screens catches of Dungeness 'A' and 'B' Power Stations in relation to their differing cooling water inlet end capping arrangements, CEGB.

| | | | | |
|---|---|---|---|---|
| Others | | 15% | 14% | 41% |
| With swimbladder | 55% | | | |
| Without swimbladder | 15% | | | |
| Shrimps | | | | 28% |

The table above contains data from the following sources:

- Turnpenny, A. W. H., J. M. Fleming, et al. (1995). Fish deterrent system at Hartlepool power station, Fawley.
- Wood, R., K. P. Thatcher, et al. (1994). Fish deterrent trials at Hinkley Point power station, Somerset 1993-1994, Fawley: 33.
- Thatcher, K. and P. W. Irving (1992). Fish deterrent trials at Oldbury power station November 1991 - January 1992, Fawley.
- Turnpenny, A. W. H. (1993). Bubble curtain fish exclusion trial at Heysham 2 Power Station February 1993, Fawley.

## *3.5 A comparison of the 0.5 fps velocity restriction versus the 12% annual impingement mortality standards.*

The two methods proposed in the rule are very different in their implementation and measurement. One is based on reducing the mortality of the fish impinged, the other on restricting the velocity of the water entering the facility.

### 3.5.1 12% annual impingement mortality standard

The 12% annual impingement mortality standard is that 88% of fish that are impinged annually should survive. This relies on extensive sampling, survival experiments, interpretation and leads to uncertainty in what the 12% reduction represents in reality. There is an additional requirement that no more than 31% of the fish impinged die in any one month.

The ability of a power plant to achieve the 88% fish survival needed to meet the annual standard will depend not only on the effectiveness of the fish handling system, but also on the species composition at the site. Some species are robust; others fragile (see Table 5). If a power plant is in an area dominated by the fragile species then it would be less likely to meet the level of survival required. The fact that some species can be ignored for the purposes of the calculation adds an additional complication. The fragile, often pelagic, species are frequently among the most abundant animals caught at cooling water intakes, and thus more likely to be ignored or under-counted.

In terms of protecting fish, by far the best method is not to impinge them in the first place. This protects the entire population, not just the better swimming individuals. Even the best fish handing systems cause fish stress. They are subjected to rapid pressure changes, physical contact and abrasions from the screens before their release back to the environment.

With the 12% rule as proposed, it is possible for an intake structure to kill 100% of the individuals of a vulnerable species that live at a low density or only represents a small percentage of the catch. The station would still meet the requirements of the rule as long as the rest of the fish were robust. Therefore, to adequately protect each species of fish, EPA should apply the 12% impingement mortality standard to each species impacted by the cooling water intake system.

The 12% annual impingement mortality standard works retrospectively, with stations having to measure their performance against the last twelve months. The penalty for failing to meet the standard is not readily apparent in EPA's proposed rule and related materials.

Monitoring of impingement mortality should be ongoing. As populations in abundance change the proportion of delicate and robust fish may vary changing the ability of the station to achieve its targets.

### 3.5.2 0.5 fps velocity restriction

To meet this standard the station must reduce the velocity of the intake water to 0.5fps at the point the fish first encounters the intake. The rule states that this will reduce impingement significantly. The Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule (2011) in section 6.18.1 states that the reduction will be 96%.

This figure of 96% appears to come from the Technical Evaluation of the Utility of Intake Approach Velocity as an Indicator of Potential Adverse Environmental Impact under Clean Water Act Section 316(b) EPRI 2000. However, this is not what the document actually says:

> *"The relevance of laboratory data has been questioned, but appears to be upheld, at least in broad terms. For example, there appears to be a positive correlation between fish that have low swimming abilities in laboratory tests (e.g., small bay anchovy, small Atlantic menhaden, Atlantic silverside, delta smelt), or fish performing at cold temperatures (e.g., juvenile salmon and trout, white perch, Atlantic menhaden, striped mullet), with the incidence of impingement at power station intakes. The corollary is also generally true that species and life stages with high swimming performance capabilities in laboratory tests are less often impinged, although this depends on various features of organism and environmental health to be discussed below. Joint analysis of power station data (retrospective) and laboratory data (predictive) is planned in conjunction with Alden Research Laboratory, which is analyzing the power station impingement data. These results are expected to be available in 2001."*

This EPRI document is suggesting that at 0.5fps 96% of fish have a swimming speed great enough to escape. The document then goes on to explain at some length why this value can vary significantly for reasons such as fish condition, temperature, dissolved oxygen, light, photo period, schooling behaviour, turbulence, disease, toxicants and acidity.

Just because a fish has the swimming ability to swim away from an intake it does not mean that they will. A fish has to understand that it is in danger and know which way to swim. In a large intake this may not be clear. The 0.5 fps limit may not be as protective as EPA suggests.

Nonetheless, short of reducing intake volume through closed-cycle cooling, the most reliable and measureable method of reducing entrainment mortality is to reduce intake velocity sufficiently to prevent impingement from happening in the first place, rather than allowing impingement to occur and attempting to return fish to the waterbody unharmed.

### 3.5.3 A comparison between EPA's two options for achieving the impingement mortality reductions.

The impingement mortality control will favour robust species over fragile ones. It may or may not be acceptable depending on the conservation issues at any particular site. The low velocity rule will favour fast swimming species and larger individuals over poor swimmers and small fish. It is possible to envision situations where one of the styles of impact is preferable over the other.

In terms of implementation, the low velocity standard is simple and is reasonably obvious in still waters, but more difficult in tidal or flowing waters, where the direction of the flow will make up some proportion of the approach velocity. The rule is unclear whether the measurements should be taken at slack water or when the ambient current is at its maximum. It is also unclear as to what level of protection the lower velocity intakes would give the fish populations.

For the impingement monitoring rule, there is a high level of complexity in the design, timing and duration of the monitoring and a considerable uncertainty in the results. It would at least measure the impact of the plant on the fish populations.

Neither system comes close to closed cycle cooling as a protective technology.

## *3.6 The additional requirements of (a) protective measures for travelling screens, (b) returns for entrapped fish, and (c) barrier nets for shellfish in coastal waters.*

Under EPA's proposal, all stations with traveling screens will have to have fish return systems and related protective measures. This will reduce the impact of the intakes, but its effectiveness will be dependent on many factors, such as design, fish handling, debris loading and the species present.

Intakes in ocean and tidal waters will need to have technologies that reduce the impact on shellfish to the level comparable with a well-maintained barrier net.

Impingement still occurs at low 0.5 fps velocities. These additional protective technologies will help in controlling the impact of the intakes and should be retained as components of the rule.

## 3.7 Conclusions

It is possible to reduce impingement at many sites using a variety of technologies. The technologies can be divided into volume/velocity reductions or some form of screening technology. To meet the standards proposed the screening technologies rely on measuring the survival of impinged fish. This has proved to be problematic over many years of study.

The most reliable method to reduce impingement by far is reducing the volume of water extracted. This is well understood and is known to work, and is achieved most effectively by closed-cycle cooling. The next is reducing the intake water velocity. Reducing the velocity of the water has been shown to reduce impingement as it allows fish that have the suitable behavioural response and the swimming ability to escape from the intake. There are many factors which will influence the reduction in the number of fish impinged when the flow is reduced. For all other methods, effectiveness will be site-specific and variable in result.

# 4 Entrainment controls

## 4.1 Introduction

The proposed rule will set the level of entrainment mortality reduction on a case by case basis. The entrainment characterization study will be used to estimate the entrainment mortality at the site. Factors such as siting, entrainment reduction technologies and flow reductions will be taken into account when assessing the entrainment.

## 4.2 Flow reduction

### 4.2.1 Closed-cycle cooling

A dry cooling system will achieve an average reduction in cooling water intake flow greater than 99 percent over a once-through system. In comparison, the average flow reduction of a closed-cycle wet cooling system for an estuarine/tidal source is around 94.9 percent, and around 97.5 percent for a freshwater source (316(b) Existing Facilities Proposed Rule - TDD Chapter 6: Technologies and Control Measures, March 2011). The EPA estimate that the reduction in entrainment mortality that this would achieve would be in the range of 97.5% for freshwaters and 94.9% for saline waters. With such reductions in flow wedgewire screens become feasible, which can further reduce the entrainment mortality to close to zero.

### 4.2.2 Variable speed pumps

As explained above, (section 3.3.5) pumps can be designed to operate at variable speeds so that when set on a lower speed they withdraw less water from the source water body. Variable-speed pumps give a plant operator the ability to tailor cooling water withdrawals to the minimum needed for cooling. Thus, the use of variable speed pumps could produce a reduction in flow for a once-through cooling system at times when higher flows are not needed.

Variable speed pumps do not provide a constant entrainment reduction benefit. They provide a benefit only when the plant is actually able to reduce flows and still generate electricity and meet thermal discharge limitations. Because of the variability in inlet water temperatures and electricity demand, it is difficult to reliably predict the effectiveness of this option for reducing flow on an annualised basis.

The reduction of entrainment of fish eggs and larvae produced by the use of variable speed pumps is particularly difficult to estimate as the presence of entrainable organisms varies greatly through the year. Obviously, reducing the water taken by the power plant during a time when there are no entrainable organisms in the water will not affect the annual level of entrainment.

## *4.3 Filtering and screening*

### 4.3.1 Cylindrical wedge-wire screens

Wedge-wire screens have a proven ability to reduce entrainment mortality at low volume intakes. As EPA notes, however, fine mesh (0.5 – 1 mm) wedgewire screens are an unproven technology for protecting once-through intakes that typically pump volumes in excess of 100 MGD[4] as they were unaware of any fine mesh wedgewire screens fitted to an intake with a flow of that magnitude.

Their effectiveness is related to (1) the slot width, (2) through-slot velocity, (3) existence and strength of ambient cross flow to carry organisms away from the screen, (4) the amount of biofouling and (5) the amount of ambient debris. They are an unproven technology for protecting once-through intakes that typically pump volumes well in excess of 100 MGD.

The reductions in entrainment possible using wedge-wire screens will be determined primarily by the slot width, the water velocity across the screen and the mix of species present at the particular locality.

### 4.3.2 Filter barriers

One potential approach for the reduction of entrainment is the protection of the cooling water intake by a meshed material of some form that is sufficiently fine to ensure fish eggs and larvae and other small organisms will not pass across the barrier and enter the cooling water system. However, if the flow per unit area through a fine mesh barrier is too high it will draw eggs and larvae onto the surface and simply replace entrainment mortality by impingement mortality. Further, eggs and larvae are soft bodied, if the flow is strong there is a risk that they will be deformed, extruded through the mesh and killed. To avoid impingement and extrusion, the surface area needs to be sufficiently large to keep the across mesh velocity low. The EPRI (2006) report *Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures* found that a slot width of 0.5 mm reduced entrainment of all fish

[4] EPA Section 316(b) TDD Chapter 5 for New Facilities Efficacy of Cooling Water Intake Structure Technologies Section 5.5.2

larvae in Chesapeake Bay by 73% and 58% at slot velocities of 0.15 and 0.3 m/s respectively. At greater slot widths and slot velocities entrainment increased. These results indicate that a flow rate of less  than 0.15 m/s or lower is required. There are many problems attaining this level of performance, and these are illustrated below for a geotextile barrier curtain termed a Gunderboom.

The Gunderboom is a structure made from a geotextile matting that is hung as a curtain across a cooling water intake to stop the entrainment of planktonic animals, particularly fish eggs and larvae. Because power stations pump considerable volumes of water, and in order to be effective the Gunderboom must have a low flow per unit area, a Gunderboom curtain must offer a large surface area to the flow. There are a number of problems with respect to the use of Gunderbooms linked to the development of biofouling communities on the fabric.

First, fouling of the surface reduces the area through which water can flow leading to velocity 'hot spots' where delicate animals may be pinned or pulled through the mesh. There is clear evidence that fouling by macro-algae does occur. In the Lovett 1999 report it is stated "The airburst system was not effective at removing algal growth from the boom". Even if they are not pulled through the filter, there is the possibility that contact with a surface may be damaging to planktonic stages that are not adapted to withstand contact with any surface. This type of problem, whether it results from passage through the filter or simply contact, can be termed mesh damage.

A second effect of increased flow resistance is the tendency of water to force another path across or around the barrier. There are three alternative pathways available to the water. (i) The water may tunnel under the bottom of the boom by displacing the sand or mud sediments; (ii) The boom may be pulled underwater resulting in flow over the boom; and (iii) The material may rip resulting in a flow via holes. Overtopping, tunnelling and rips have all been observed during testing. For example, in the Lovett evaluation report for 1999 it is stated that "the divers documented a substantial gap along the bottom of the boom …. the gap extended along the bottom of the boom for approximately 3 m and ranged in depth from 0.5 to 0.6 m". The problem of water not flowing through the barrier is termed mesh avoidance.

A third major problem relates to the establishment of a predatory community that feed on any small animals drawn close to the mesh. A fouling community adapted to feed upon any organisms drawn onto the filter may develop. If the flow is maintained at very low levels this may be unimportant, but if flow differentials become established, then weakly swimming or non-swimming life stages may become held against or close to the surface for sufficient time to be attacked.

### 4.3.3 Fine mesh screens

Fine mesh screens, with mesh sizes of less than 5mm, have been installed on conventional traveling screens to reduce entrainment. Fouling and clogging are major issues with this screening technology and the increased size of the screens needed to maintain a low speed across the mesh makes retrofitting difficult. The main problem with fine mesh traveling screens it that they convert entrainment into impingement, and can simply transfer the mortality from one category to another. The EPA found that impinged small fish have a very low survival, with the larval stage often having greater than 80% mortality.

### *4.4 Conclusion*

All methods based on filtering out planktonic life forms to reduce entrainment at large once-through cooled power plant are problematic and unreliable. The area of screening needed to filter the volumes of water used by a once-through cooling system is very large, and because of this, poses many problems for fine filtering methods. The surest method to reduce entrainment is to reduce the amount of water taken in by the plant. The best method for volume reduction is the use of closed-cycle cooling. For example, using cooling towers will reduce the volume of cooling water extracted by well over 90%. With these lower flows other protective technologies such as wedge wire screens become practical.

## 5 Other issues

### *5.1 The calculation of the percentage standards are based on very few studies.*

The EPA reviewed survival experiments for impingement studies and found only 3 that met their selection criteria. These stations were all older style plants in in New York State. This a very limited sample of the possible range of stations, and may well bias the values used in the calculations. The stations used are Arthur Kill, Dunkirk and Huntley.

Even within the data there is considerable variation in the mortality rates depending on the season.  For example to mortality rate at Dunkirk in the summer is 14.9% and in the fall is 2.7%. This is a considerable range and suggests that the season that the experiments were undertaken is important. For the Huntley data there were only two periods of experiments, on in January and one in October.

In conclusion there is very little data to support the rule, and that data used are difficult to interpret. If the data was for newer plants, and for a wider cross section of plants, the survival results might well be higher and the resulting standards stricter.

### *5.2 Percentage of biomass transferred from one life stage to another.*

In estimating the benefits of the reduction in fish kills the EPA has made assumptions on the amount of biomass that moves from the calculated age 1 equivalent.

*"EPA used a simple trophic transfer model for this purpose (discussed in Chapter A-1 of EPA's Regional Benefits Analysis (USEPA 2006b), assuming a trophic transfer efficiency of 0.10 (Pauly and Christensen 1995). Trophic transfer efficiency represents the fraction of forage species biomass incorporated into predator (fishery) species biomass."*

This is a gross generalisation for aquatic ecosystems, and while it is probably of the correct order of magnitude, there is a lot of variation between different habits. In the same paper Pauly and Christensen (1995) point out that the primary production required to produce the harvestable biomass varies greatly, from about 2% of the primary production in the open ocean to about 36% in non-tropical shelves. For the two habitats most likely to be impacted by US power plants, coastal/reef systems and rivera and lakes the values are 8.3% and 23.6% respectively.

The actual transference of energy from one trophic level to another can vary massively between different habitats as well. Pauly and Christensen reviews 140 studies and find the mean transference between trophic levels is 10%. The plotted data shows that the actual estimates range from below 2% to over 24%.

This type of analysis is very simplistic, as it assumes that fish are always at the same trophic level. This is not true, as many species change diet considerably with age. Many fish species start their lives feeding of small planktonic organisms, before growing and feeding on larger invertebrates and becoming largely piscivorous as adults.

Another factor that cannot be taken into account is how the transfer of energy has been affected by the actions of man. It may be that, before the development of modern fishing techniques which tend to disproportionally take larger fish from a population, much more of the biomass a system was in large predatory fish. This would change the rate at which energy transfers though the system.

In summary, the efficiency with which food passes from one trophic level to another is very difficult to estimate. It will certainly vary greatly from ecosystem to ecosystem and from species to species.

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# CURRICULUM VITAE

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## ACADEMIC QUALIFICATIONS AND POSITIONS

**BSc 1st Class Honours Zoology and Applied Entomology**: Imperial College, London.

**PhD, DIC, University of London, Thesis :-** Population Studies and Behaviour of *Cypridopsis vidua* (Muller), (Crustacea, Ostracoda)

**Senior Research Associate, Dept., of Zoology, University of Oxford.**

**Visiting Research Fellow, University of Southampton.**

## EXPERTISE AND EXPERIENCE

An ecological consultant and research scientist with 30 years experience combining theoretical, applied and field research. Extensive experience of the management of major ecological assessment projects including preparation and presentation of material for public enquires and liaising with conservation bodies and engineers. Projects undertaken include conservation planning for large tropical nature reserves, ecological effects studies of nuclear power station intakes, conservation studies of rare freshwater life and effects of climate change and drought. I lecture and hold a position as a senior research associate in the department of Zoology, University of Oxford.

## PROJECT INVOLVEMENT

### INDUSTRIAL ECOLOGY

Wide experience in power plant cooling water engineering including the preparation and presentation of evidence at public inquires and the writing of environmental impact assessments. Studies in the USA for Riverkeeper have included work on the effectiveness of Gunderbooms for minimising entrainment, analysis of the DEIS for Indian Point, Bowline 1, 2 & 3, Lovett, Roseton and Albany power plants. Work for the Natural Resources Defence Council include assessment of the impact of the Astoria Repowering Project in New York. Considerable recent experience working on fisheries issues linked to power plant proposals in the Hudson

River, New York and Morro Bay, California. Extensive work has been carried out for Riverkeeper on the US Environmental Protection Agency's (EPA) 316b legislation on cooling water intakes.

Project management of major UK environmental impact studies including Sizewell B , Hinkley C and Fawley B power stations, the Severn tidal barrage scheme and the Usk Barrage. Other projects have included marina developments and ecological issues of importance to ports. I have acted as a fish and fisheries expert witness on the London Gateway Project for Pacific & Orient Shipping Company with respect to the London Gateway port proposal and as an advisor for the Bristol Port Company. I have also acted as an expert witness on the effects of aggregate dredging and the effects of outfalls on salmon movement.

A particular area of expertise is on the impingement and entrainment of fish and crustaceans at coastal and estuarine intakes in the British Isles. I have worked on this field for more than 26 years and hold the largest data set on impingement of fish in existence.

## TROPICAL ECOLOGY

Fisheries research manager and ODA consultant on fisheries and aquatic ecosystems for Project Mamiraua in the upper Amazon. Tropical research has been varied and includes work on the taxonomy of Amazonian fish, behaviour of electric eels and the community structure found around leaf litter and floating meadow habitats.

## ECOLOGICAL STUDIES

### BRITISH ESTUARINE AND RIVERINE COMMUNITIES

More than 26 years of study of British estuarine fish and crustacean population dynamics. Studies undertaken of community dynamics, wood webs, climatic effects and predator-prey interactions. Recent work has concentrated on the effects of climate change on fish. I have particular expertise in the Bristol Channel/ Severn Estuary and the Thames Estuary.

### CONSERVATION MANAGEMENT PLANNING

Wide range of projects undertaken including a senior role in the planning of one of the world's major freshwater reserves, the Mamirauá reserve in Brazil. Responsible for the development of the aquatic strategic management plan for an area of 1,124,000 ha of Amazonian flooded forest holding diverse habitats including lakes, varzea forest, rivers, stream and floating meadows. The project has developed many novel ways of conserving fish and other aquatic species and is recognised as one of the great success stories of international conservation.

### INVERTEBRATE TAXONOMY

Author of the Freshwater Ostracods book in the series Synopsis of the British Fauna series. Taxonomic studies also undertaken on mysids, shrimps and fish.

### BIOLOGICAL AND STATISTICAL SOFTWARE

The designer and developer of computer based expert systems, including the commercial software packages E3 (for environmental effects evaluation which is available from The Stationary Office), Species Richness and Diversity (available from PISCES), Community Analysis Package (available from PISCES) and Dynamica (available from Chapman & Hall). I designed and developed PISCES, an expert system used to predict fish and crustacean impingement and entrainmnet at power station intakes. Most recently, I designed and wrote with Dr Richard Seaby QED Statistics, which is a general statistic package.

### POPULATION BIOLOGY

Including the study of fish, ostracod, crustacean and insect populations in many diverse habitats. I lecture in population dynamics at the University of Oxford. I published with Sir Richard Southwood on long-term changes in insect populations.

## LECTURING AND WRITING

### LECTURER AND SUPERVISOR

An experienced supervisor of post-graduate students. Lecturer and tutor on the climatic change masters coarse at the University of Oxford.

### WRITING AND BROADCASTING

Freelance writer for British Wildlife and other magazines. Occasionally working as a scientific advisor for the BBC and other television companies. Lecturer to natural history clubs and societies on rain forests, tropical fish and British wildlife.

## PROFESSIONAL HISTORY

**Present positions: Director PISCES Conservation Ltd. & Senior Research Associate, Dept. of Zoology, University of Oxford**

**Employer** : Department of Zoology, University of Oxford.
**Position** : Senior Research Associate and lecturer(1994-1999).
Lecturing on ecological methods and population dynamics. Research undertaken on; (1) the limnology of Amazonian floodplain systems with particular emphasis on micro crustaceans and floating meadow fish communities and population; (2) Population dynamics of fish and crustaceans the Bristol Channel; (3) Population and community dynamics theory with Professor W. D. Hamilton. During my time at Oxford I also completed a revision of the standard textbook *Ecological Methods* with Professor Sir Richard Southwood.

**Employer** Projeto Mamiraua
**Position** Fisheries and Aquatic ecology consultant (1989-1997)
Responsible for management and creation of the initial research and development plan for the reserve and subsequent research on biodiversity.

**Employer** : Fawley Aquatic Research Laboratories Ltd.
**Position :** Director (1991-1994)
Responsible for software development, mathematical modelling, statistics and marine and estuarine impact assessments of power stations.

**Employer** : Central Electricity Research Laboratory and National Power PLC
**Position :** Research Scientist (1978-1991).
Working on the development of mathematical models of natural systems. Major research areas were (i) population biology of marine fish and crustaceans: (ii) the modelling of water movement and cooling water discharges: (iii) the causes of red tides: (iv) freshwater community structure in relation to water chemistry changes caused by acid rain.

## OTHER POSITIONS HELD

2008- Assistant editor Journal Marine Biological Association of the United Kingdom.

1998-2001 Council of the Fisheries Society of the British Isles.

1984-1990. Assistant editor of the Journal of Fish Biology

1987 – 2001. Director of Biological Computing Systems Ltd.

1987-1990. Council of the Linnean Society.

1988 - Associate with John Grimes Partnership - consulting engineers.

1985 -Visiting research fellow for the International Atomic Research Agency.

1983- Research professor for BIDS project Brazil.

## EXTERNAL PUBLICATIONS

### BOOKS

**Henderson** & Margetts (Eds), 1989. Fish in Estuaries. Fisheries Society of the British Isles.

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**P.A. Henderson,** Seaby, R.M.H. & Somes J.R. (2011) Community level response to climate change: The long-term study of the fish and crustacean community of the Bristol Channel, Journal of Experimental Marine Biology and Ecology, DOI: 10.1016/j.jembe.2011.02.028.

# CURRICULUM VITAE

## DR RICHARD MILES HARRINGTON SEABY

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**E-mail richard@pisces-conservation.com**

## ACADEMIC QUALIFICATIONS

**B.Sc. 2:1 Hons Biology (1984-1987).** Goldsmiths College, University of London.

**Ph.D. Aquatic Ecology (1988-1992)**. University of Liverpool. Thesis : - *Coexistence of Lake-Dwelling Triclads and Leeches*.

## EXPERTISE AND EXPERIENCE

I am an ecologist consultant specialising in the aquatic habitat, with over 20 years of experience in the ecological effect of industrial and engineering projects. I have been running Pisces conservation for over 15 years, in which time we have grown into the UK foremost consultancy on the environmental effects of large industry on the aquatic environment.

Projects undertaken have included the ecological impacts of power stations, both nuclear and conventional, the impact of thermal outfalls on migratory fish, the mortality of entrained fish and crustaceans, the efficiency of various methods of reducing impingement and entrainment mortality, the impacts of dredging on fish and the long term monitoring of estuarine fish and crustacean populations. I have worked extensively in both freshwater and marine environments, and have held licences to handle Red Data Book species. I also have many years' experience in computer simulation and modelling, and software development, and a considerable peer-reviewed publication list.

## PROJECT INVOLVEMENT

### POWER STATION/INDUSTRIAL ECOLOGY

I have undertaken a wide range of power station and industrial projects in both the UK and the USA. Work includes examination of the effects of FGD plants in fresh and marine environments, entrainment / impingement studies, and the effects of the US Environmental Protection Agency’s 316b legislation on cooling water intakes. Recent studies on marine ecology in the UK include the effects of dredging for sand in the Severn estuary, reports on the London Gateway container port proposal, and the ecological impact of FGD plants on the Thames and in the Severn estuary. In the USA, I have worked on the fishery issues related to several power stations in the Hudson River, NY, power station re-powering issues in the Great Lakes and desalination plants in California. Some example projects are summarised below.

### THE EFFECT OF THERMAL EFFLUENTS ON THE MIGRATION OF SALMON

Projects have been undertaken in the Southampton Water SAC and in Milford Haven, modelling the impact of thermal plumes on the migration behaviour of Salmon. Undertaken for the EA.

### LONG TERM POPULATION STUDIES IN THE SEVERN ESTUARY

I have been involved with this study for 20 of its 30 years. This project has become particularly important in recent years with the Estuary becoming a special area of conservation (SAC). This work has involved liaising with MAFF, English Nature, WWF, EA, British Energy and EDF. This work has produced a dataset that is now regarded as internationally important in the understanding of fish populations.

### SURVIVORSHIP TRIAL OF THE FISH-RETURN SYSTEM AT SIZEWELL 'B' POWER STATION

Project management of a study of the efficiency of fish return systems at Sizewell B nuclear power station. The work was undertaken for British Energy.

### DESALINATION PLANTS

The impact of high temperature and high salinity plumes on the Californian coast.

### FLUE GAS DESULPHURISATION

Reports on the impact of two proposed FGD plants on the Thames and the Severn estuary.

### FOAMING AT OUTFALLS

Monitoring and reporting on the production of foam and the related water quality issues. This is an area where more and more stations are having issues.

### THE EFFECT OF WATER ABSTRACTION ON THE SALMON MIGRATION IN THE RIVER ITCHEN

To aid the study of water extraction on the movement of salmon, Pisces have produced several reports for the NRA and latterly EA. This work has included creating Markov chain models for the movement of fish from the estuary to the river, and analysis of the transfer probabilities of the salmon in relation to flow.

### GUNDERBOOM FOULING AND PERMEABILITY STUDIES IN THE HUDSON RIVER, NEW YORK, USA

Investigations into fouling organism growth on a permeable membrane used to reduce fish impingement at power stations. Studies of the bacterial, fungal and macroinvertebrate were undertaken over 2 months. The permeability was examined in relation to the degree of fouling found.

### GRAVEL EXTRACTION IN THE SEVERN ESTUARY AND ITS EFFECT ON THE WHELK FISHERY

Samples were taken from within the whelk fishing grounds, and the area of sand and gravel extraction was shown not to contain significant whelk numbers.

### THE EFFECTS OF LOW FLOWS ON INVERTEBRATE COMMUNITIES

Several studies have been undertaken on the effects of low flows to streams and rivers around Britain. The invertebrates have been identified to species level and LIFE scores calculated.

### WEYMOUTH BAY: FISH AND FISHERIES REVIEW

A review of the economic and social importance of the fisheries within Weymouth Bay. This involved liaison with MAFF, Southern Sea Fisheries and local fishing organisations.

## ECOLOGICAL STUDIES

### BEXHILL - HASTINGS RELIEF ROAD

Survey for fish and white-clawed crayfish in several rivers affected by the proposed development.

### THE IMPACT OF A HOUSING ESTATE ON A LAKE

The investigation of a lake where a large housing development was built. The investigation focused on the likely impact and the possible spread of invasive species.

### INFILL OF CHALK AND GRAVEL PITS AND THE DEVELOPMENT OF WILDLIFE HABITATS

Advice on the ecological quality of the habitats, the plans and improvements required to satisfy the regulatory bodies.

### REPORT ON WATER QUALITY IN THE KEYHAVEN RESERVE

Water quality data for Keyhaven stream and two other small streams flowing into Keyhaven reserve indicated that these streams were receiving ground water inputs. As this water was derived from a gravel pit in the vicinity of a rubbish dump, there was a high risk that Keyhaven pond was receiving elevated heavy metal inputs. This threat to the reserve and the problem of a reduction in dissolved oxygen concentration caused by the discharge of iron-rich ground water were discussed.

### A STUDY OF THE AQUATIC HABITATS OF HYDE AND GORLEY COMMONS.

As part of an environmental review of a new nature reserve, we performed a baseline study of the habitat. This showed the presence of the Fairy shrimp, *Cheirocephalus diaphanus.* The report detailed a management plan for the aquatic habitats and creative conservation ideas for improving the reserve.

### MOLLUSCAN FAUNA OF THE CHITTERNE BROOK, WILTSHIRE.

Analysis of molluscs living in a small stream, undertaken for Wessex Water. The work required identification to the species level.

### INVERTEBRATES IN LINCOLNSHIRE SPRINGS AND STREAMS.

A quantitative study of the freshwater invertebrate fauna undertaken for Anglia Water. All major invertebrate groups were identified to the species level.

### THE IMPACT OF A MANAGED RETREAT ON THE INVERTEBRATE FAUNA OF A SALTMARSH.

A study of the invertebrates in marshland bordering the Severn estuary, monitoring the development of a saltmarsh community following deliberate breaching of sea defences on the River Axe in North Somerset..

### THERMAL MODELS FOR POWER STATIONS

Asses and develop thermal modes at a range of power related thermal discharges. Including measuring in site, predicting the effects and estimating the size and duration of plumes.

### TRANSECT WALKER

Developed the software used by Butterfly Conservation to collate and analyse butterfly monitoring data on a national level..

### LARGE SCALE IMPINGEMENT STUDIES

Surveying the impingent of fish at the sites of two proposed new build nuclear power plants, estimating the total catch of fish and invertebrates for a range of methods.

## COMPUTER PROGRAMS

### COMMUNITY ANALYSIS PACKAGE AND ECOM

Two programs to perform the commonly used community analysis methods. Cap calculates TWINSAPN, PCA, DECORANA, Cluster analysis, MDS, association analysis and many more. ECOM performs Canonical

Correspondence analysis. All methods are easy to use and presented in a familiar Window environment. These programs are used all over the world.

## SPECIES DIVERSITY AND RICHNESS

This is a commercially available windows program that has been developed to simplify the use of diversity indices and richness estimators. It calculates all the commonly used diversity indices and richness estimators. In addition, it also can calculate diversity ordering graphs, which is probably the most powerful methodology available for establishing differences in diversity between samples, fit data models simulate data and perform specialist analysis.

## QED STATISTICS

A general statistics program aimed at the teaching market.

## FUZZY GROUPING

A program using fuzzy logic to create groups in ecological data.

## DYNAMICA II

A program which allows the investigation of community of fish and crustaceans in the Severn Estuary. Program is based on a 19 year time series of 75 species of fish and 8 species of macro crustaceans collected from Hinkley Point Power station.

## PISCES EXPERT SYSTEM

The development of an expert system to predict the impingement of fish and macro-crustaceans on industrial intakes around Britain

## E3

An Environment Management System designed to help companies achieve BS 7750 and ISO 14000.It performs the Environmental effects evaluation of a company and forms the various environmental registers required by these standards. Published by The Stationary Office

## BUTTERFLY TRANSECT PROGRAMS

A suite of programs for Butterfly Conservation to hold and analyse the data from hundreds of volunteers.

## RADIONUCLIDE DISPERSAL MODELLING

A training module for Royal Navy engineers at HMS Sultan

## MARINE BIOTOPE MATCHING PROGRAM FOR THE JNCC

A major project to identify samples to their biotope for the Joint Nature Conservation Council.

## OTHER PROGRAMS INCLUDE

Growth, Simply Tagging, Density from Distance, Axis, Community Sequence Analysis, Simply Probit, Removal Sampling, Hedgerow Assistant

# PROFESSIONAL HISTORY

**Present positions: Managing Director PISCES Conservation Ltd.**

**Employer** : Fawley Aquatic Research Laboratories Ltd.
**Position :** research Scientist (1992-1995)
Fisheries science, including tagging studies, impingement and entrainment studies and fisheries reviews. Also the development of several software products.

**Employer** : Central Electricity Research Laboratory and National Power PLC
**Position :** Assistant Scientist (1990-1992).
Summer work on shrimp populations around Britain..

# EXTERNAL PUBLICATIONS

## BOOKS

Henderson, P. A. and **Seaby R. M. H.** (2008) *A Practical Handbook for Multivariate Methods*. Pisces Conservation Ltd., 223pp.

## PAPERS

Henderson P A., **Seaby R. M. H.** & Marsh (1990). The population zoo geography of the common shrimp (*Crangon crangon*) in British waters. J. Mar. Biol. UK. 70, 89-97.

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Young J.O., **Seaby R.M.H**..& Martin A.J., 1995. Contrasting mortality in young fresh water leeches and triclads. Oecologia 101:317-323

**Seaby R.M.H.**, Martin A.J.& Young J.O., 1996. Food partitioning by lake-dwelling triclads and glossiphoniid leeches: field and laboratory experiments. Oecologia 106: 544-550

**Seaby R.M.H.**, Martin A.J.& Young J.O., 1996. Inter relationships between lake dwelling triclads and leaches: field and Laboratory experiments. Oecologia.

**Seaby, R.M.H** & Henderson, P A, 1996 The Dynamic patterns of fish and crustacean populations in the Severn Estuary, England, Oceanologica Acta,

Henderson, P. A. & **Seaby, R. M. H**. (1999). Population stability of the sea snail at the southern edge of its range. J. Fish Biol. 54, 1161-1176.

Bamber, R. N. and **Seaby, R.M.H.**, 2004. The effects of power station entrainment passage on three species of marine planktonic crustacean, *Acartia tonsa* (Copepoda), *Crangon crangon* (Decopoda) and *Homarus gammarus* (Decapoda). Marine Environmental Research 57: 281-294

Henderson, P. A. & **Seaby R. M. H.** (2005) The role of climate in determining the temporal variation in abundance, recruitment and growth of sole *Solea solea* (L) in the Bristol Channel. J. Mar. Biol. Ass. UK. 85 197-204.

Henderson, P. A. **Seaby, R. M. H.** & Somes, J. R, 2006. A 25-year study of climatic and density-dependent population regulation of common shrimp, *Crangon crangon*, in the Bristol Channel. J. Mar. Biol. Ass. UK. 86, 287-298.

## NON SCIENTIFIC PUBLICATIONS

Bass catches not hit by surveys. Fishing news 26 August 1994.